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# Flumes, Historic Water Yield
# and
# Climatological Data
# for
# Tenderfoot Creek Experimental Forest, Montana



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Flumes, Historic Water Yield and Climatological Data

for

Tenderfoot Creek Experimental Forest,

Montana

Final Report

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Between

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## Acknowledgments

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## Introduction

The objectives of this Research Joint Venture Agreement (RJVA) were to install and calibrate three flumes on Tenderfoot Creek Experimental Forest (TCEF) in central Montana; check calibration of the existing seven flumes on TCEF; estimate the influence of fire on water yields over the 400-year fire history period; and estimate back records of monthly temperature, monthly snow water equivalent, monthly precipitation for TCEF, and monthly streamflow for the lower Tenderfoot Creek flume (Tenderfoot Creek below Stringer Creek). Because of the potential for high streamflows in 1997, and the potential for low flows in 1998, we postponed this report so that 1997 and 1998 streamflow data could be included in the streamflow analysis. The information shown in this report completes the requirements for this RJVA.

## Pack Creek Flume Installation (Pack Creek Near Mouth)

A 2-foot Parshall flume was obtained from the Beaverhead National Forest. To accommodate higher streamflows, additional sidewall extensions were constructed and bolted to the flume, an inlet nipple for attaching the stilling well was welded to the flume, a staff gage was installed in the flume across from the stilling well inlet and the stilling well and water level recorder cover were constructed. The flume and all installation materials were shipped to the site on July 17, 1996, with a helicopter contracted through the White Sulphur Springs District Office (Jet Ranger II operated by Charlie Rogers of Central Air Service of Lewistown, Montana). The flume was installed between August 5 and 22, 1996. The recorder was installed and a rating table developed by September 5, 1996, making the site fully operational. Detailed information is on file at the Forestry Sciences Laboratory in Bozeman, Montana.

## Upper Stringer Flume Installation (Stringer Creek Above East Fork)

A 3-1/2-foot H-flume stored at the Forestry Sciences Laboratory in Bozeman, Montana, was readied for installation. A stilling well and instrument shelter cover were constructed and a staff gage was installed in the flume. The flume and shelter were disassembled and shipped to the site on July 17, 1996, by helicopter. All installation materials were also prepared and shipped to the site by helicopter the same day. The flume and instrument shelter were installed between August 5 and 22, 1996. The recorder was installed and a rating table developed by September 5, 1996, making the site fully operational. Detailed information is on file at the Forestry Sciences Laboratory in Bozeman.

## Passionate Creek Weir Installation (Passionate Creek Near Mouth)

A 4-foot Cipolletti weir was constructed by Midwest Welding of Bozeman, Montana, and prepared for installation. A stilling well and instrument recorder cover were constructed. A staff gage was installed on the flume. The flume, stilling well and all installation materials were prepared and shipped to the site on July 17, 1996, by helicopter. The weir and stilling well were installed between August 5 and 22, 1996. The recorder was installed and a rating table developed by September 5, 1996, making the site fully operational. Detailed information is on file at the Forestry Sciences Laboratory in Bozeman.

## Calibration of Existing Flumes

Current meter readings were made at existing flumes. Some problems were encountered since cross-sections from which to accurately gage the streamflow were poor, except at the flume sites. At the flume sites, particularly the H-flumes and Cipolletti weir, the flow regime was disrupted by the flumes. It was decided that the standard calibration values for these flumes were more accurate than the streamflow estimates that could be made with the current meter. It was concluded that the existing calibrated ratings would be the most accurate method to use to obtain flow data, particularly throughout the full range from low to high flows. Also, access was difficult during high flows, and fluctuations from wave action during high flows made it difficult to obtain accurate staff gage readings which were compared to current meter readings. In general, flows measured with the current meter were within 5 to 10 percent of flows determined with rating curves.

## Influences of Historic Fire on Water Yield

Records of fire history, interception of snow and precipitation and relationships with runoff were used to develop a formal presentation on "Historic Role of Fire in Determining the Natural Variability of Annual Water Yield in Mountain Watersheds" which was presented at the Western Snow Conference in Banff, Alberta, in May 1997. Principal investigators in this RJVA were co-authors. A copy of this paper is included in Appendix I.

## Historic Monthly Temperatures

Average maximum (TMax) and minimum (TMin) monthly temperatures were estimated by comparing weather station records at Onion Park with climatological stations at White Sulphur Springs, Neihart and Kings Hill and SNOTEL sites at Spur Park and Deadman Creek. Estimates of historic monthly average TMax and TMin temperatures for Onion Park are shown in Appendix II. Relationships and techniques used to estimate historic temperatures are on file at the Forestry Sciences Laboratory in Bozeman.

## Historic Monthly Snow Water Equivalent

Snow water equivalent (SWE) measured at snow courses on TCEF were summarized and compared to NRCS snow pillows at Spur Park (8,100 ft) and Deadman Creek (6,450 ft) located approximately 15 miles ESE of TCEF. The Kings Hill snow course (7,500 ft) about 12 miles ESE of TCEF was also compared. Correlations between individual snow courses and the average of eight TCEF open snow courses and estimated historic SWE for TCEF are shown in Appendix III. Procedures and techniques used to estimate historic SWE are on file at the Forestry Sciences Laboratory in Bozeman.

## Historic Monthly Precipitation

Monthly precipitation values measured at storage gages and electronic tipping buckets at data sites on TCEF were summarized and compared to NRCS SNOTEL stations at Spur Park and Deadman Creek, and the discontinued climatological station at Kings Hill. Correlations

between individual stations and the average of eight sites and estimated historic monthly precipitation for TCEF are shown in Appendix IV. Relationships and techniques used to estimate historic precipitation are on file at the Forestry Sciences Laboratory in Bozeman.

## Historic Monthly Streamflow

Because of the potential for high streamflows in the spring of 1997 and low flows in 1998, it was decided to wait until 1998 records were available to complete correlations. The only long-term stream gage records available for cross-correlation are from Sheep Creek near White Sulphur Springs. Flows were divided into periods to represent base, winter, spring and summer flows. Correlations and estimates of historic flow for Tenderfoot Creek below Stringer Creek (lower Tenderfoot flume) are shown in Appendix V. Procedures and techniques used to estimate historic streamflow data are on file at the Forestry Sciences Laboratory in Bozeman.

## Applications Research

To date, the data provided by this study has been used by Chad Moore for his master's thesis, "Snow Accumulation Under Various Successional Stages of Lodgepole Pine", Earth Sciences Department, Montana State University; Tess Brennon, Earth Sciences Department, Montana State University, who is doing her master's thesis on whitebark pine; and Jeff Boice, Earth Sciences Department, Montana State University, for his master's thesis on "Analysis of Morphometric Variability for First and Second Order Streams in the Tenderfoot Creek Experimental Forest". There are also various other ongoing studies by USFS researchers.

APPENDIX I.  INFLUENCE OF HISTORIC FIRES ON WATER YIELD OF TENDERFOOT CREEK EXPERIMENTAL FOREST

The historic role of fire relative to runoff in the Tenderfoot Creek Experimental Forest was investigated.  The results were presented in a technical paper.  This paper was presented at the 66th Annual Western Snow Conference, May 5-8, 1997, in Banff, Alberta, Canada, and was published in those proceedings.  An updated copy of this technical paper is included.

# HISTORIC ROLE OF FIRE IN DETERMINING THE NATURAL VARIABILITY OF ANNUAL WATER YIELD IN MOUNTAIN WATERSHEDS

by

Ward W. McCaughey,[1] Phillip E. Farnes,[2] and Katherine J. Hansen[3]

## ABSTRACT

Management of forested watersheds should be based on information that accurately reflects the historic natural range of variability of historic water yields. Water yields from mountain watersheds depend on total precipitation input, the type and distribution of precipitation, canopy interception, and losses to evaporation, transpiration and groundwater. A systematic approach was developed to estimate the natural range of variability of average annual runoff based on historic fire patterns, habitat cover types and precipitation patterns on the Tenderfoot Creek Experimental Forest, Montana USA. The systematic approach developed correlations between measured values of average annual runoff and precipitation, forest canopy cover and precipitation reduction, forest canopy cover and habitat cover type, winter precipitation reduction and habitat cover type and effective precipitation and average annual runoff. Historic average annual runoff was then estimated for fire-generated stands before and after a fire year.

A fire history study on the experimental forest indicates that much of the watershed burned in the 1700s and 1800s. Two fires occurred in the 1700s and six in the 1800s covering more than 45 percent and 65 percent of the experimental forest, respectively. Only three small fires totaling 19 ha have occurred since the initiation of fire suppression in the early 1900s.

Annual water yield was estimated for the experimental forest for the past 400+ years. Maximum average annual runoff was estimated at $12.48 \times 10^6$ cubic meters ($m^3$) for the late 1500s after a considerable portion of the watershed was burned and the 1581 to 1997 average water yield was estimated to be $11.68 \times 10^6$ $m^3$. The maximum average water yield if all timber were removed, is estimated to be $13.24 \times 10^6$ $m^3$. The minimum average annual runoff if the entire forest consisted of mature lodgepole pine is estimated to be $11.23 \times 10^6$ $m^3$. The present yield of $11.36 \times 10^6$ $m^3$ approximates the lowest yield of $11.25 \times 10^6$ $m^3$ and is near the minimum possible for this experimental forest. Current fire suppression coupled with succession has decreased water yields close to minimum levels in many watersheds and created forest conditions conducive to catastrophic fires. Forest management that reflects natural variability could create a mix of successional stages, reduce fire potential and maintain increased water yields within natural hydrologic limits.

## INTRODUCTION

This paper presents the computational procedures for estimating 400 years of average annual water yields and provides estimates of the natural range of water yield variability based on fire history patterns, annual precipitation and habitat cover types. Current hydrologic models predict effects from vegetation management but do not adequately reflect the natural range of variability of annual water yield from watersheds. Hydrologists use computer models to predict the potential effects of vegetation manipulation on water yield from watersheds. Watershed models such as WATSED (Water and sediment yield model—USDA Forest Service 1991) and WATBAL (Water balance model) provide hydrologists with information on projected water and sediment yields based on levels of vegetation management. Information from these models are used in the management of watersheds where hydrologic limits are placed on management activities based on bank full and peak flows estimates.

There are no known models that incorporate fire history into water yield predictions.

Historic water yield information is needed to determine the natural range of variability of water yields so that hydrologic limits can be correctly determined. Decisions to manage vegetation within watersheds are based on a variety of factors including protection of threatened or endangered species, wildlife habitat protection and the hydrologic limits. Hydrologists have minimal to no long-term historic streamflow data on undisturbed or disturbed watersheds. Streamflow data for only the past 20 to 80 years may not accurately indicate the natural range of variability of historic water yields from mountain watersheds because of fire suppression.

Snowmelt accounts for 50 to 70 percent of the total annual runoff in lodgepole pine and spruce/fir stands of the Northern Rockies (Farnes 1978). Water yield can be increased in subalpine forests through the use of prescribed fire or other management techniques such as harvesting. Openings created by fires or through forest management increase snow accumulation, decrease sublimation losses and increase water yields (Gary and Troendle 1982). Partial cutting reduces winter interception loss and summer soil water depletion due to shading effects of the remaining overstory (Troendle 1986).

Precipitation inputs, water yield outputs and forest canopy interception data have been collected on the Tenderfoot Creek Experimental Forest (TCEF), Montana USA, since 1992. The experimental forest was used for this study because it is representative of subalpine fir (*Abies lasiocarpa*) forests composed primarily of lodgepole pine (*Pinus contorta* Dougl. var. *latifolia*). This forest type covers six million hectares (ha) of commercial forest lands in the Rocky Mountains (Koch 1996; Wheeler and Critchfield 1984), and therefore the results of this study have wide geographic applicability. Mountain watersheds are important catchment basins for precipitation used for irrigation, hydroelectric generation and recreation. These watersheds provide high quality drinking water for municipalities and aquatic and riparian habitats for fish, aquatic insects, waterfowl and a host of wildlife species such as beaver (*Castor canadensis*), moose (*Alces americana*) and dippers (*Cinclus mexicanus unicolor*).

STUDY LOCATION

The Tenderfoot Creek Experimental Forest covers 3,709 ha of the headwaters of the Tenderfoot Creek watershed located in the Little Belt Mountains in central Montana. The experimental forest, established in 1961 for watershed research, has an average annual precipitation of 890 millimeters (mm) that varies from 595 mm in the lower elevations to 1,050 mm in the higher elevations. Elevations range from 1,838 to 2,421 meters (m) with an average of 2,206 m. Fire suppression since the early 1900s has reduced the effects of fires on the experimental forest (Barrett 1993).

The experimental forest is currently about 9 percent non-forested, 42 percent is in single-aged stands and 49 percent is in two-aged stands. The geology, soils, and stand conditions within the experimental forest are fairly consistent, providing a near-optimum site to isolate the influence of canopy coverage and habitat cover type on runoff. The oldest stands on TCEF were last burned in 1580, and the most recent burn affecting a large area occurred in 1902 (Table 1). The 1580 burn is currently a mature Engelmann spruce/subalpine fir (*Picea engelmannii/Abies lasiocarpa*) stand with a few isolated mature lodgepole pine found where mortality has created gaps in the overstory. From 1580 to 1902, ten fires occurred with an average fire size of 621 ha and an average of 32 years between fires. Three small burns (average size of six ha) in 1921, 1947 and 1996 (32 years between fires on the average) have affected less than 20 ha or less than 1 percent of the experimental

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forest in the last 95 years. In contrast, 1,660 and 2,415 ha have burned in each of the two preceding centuries (Table 1).

Table 1.    Year of fire, area burned and percent burned of total area of Tenderfoot Creek Experimental Forest (Barrett 1993, unpublished report).

| Year | Size (ha) | Percent of total area |
|------|-----------|----------------------|
| 1580 | 1900 | 51 |
| 1676 | 32 | 1 |
| 1726 | 1108 | 30 |
| 1765 | 552 | 15 |
| 1831 | 41 | 1 |
| 1845 | 1008 | 27 |
| 1873 | 1317 | 36 |
| 1882 | 30 | 1 |
| 1889 | 19 | <1 |
| 1902 | 206 | 6 |
| 1921 | 8 | <1 |
| 1947 | 11 | <1 |
| 1996 | 0.4 | <1 |

## METHODS

We used a six-step approach to estimate average annual runoff on the Tenderfoot Creek Experimental Forest. This process involved the development of mathematical relationships between a variety of variables. In step one, average annual runoff measured on Tenderfoot Creek over the past five years was correlated with accumulation and precipitation data from nearby weather stations and SNOw survey TELemetry (SNOTEL) sites. These correlations were used to estimate the averages for 30 years(1961-1990) of average annual runoff, April 1 snow water equivalent (SWE), April through June precipitation (rain) and average annual precipitation on TCEF (Figure 1). July through September precipitation was not considered to affect runoff in this study. This late summer precipitation added little to stream runoff because of high evaporation rates, increased water use by vegetation and high soil moisture deficits.

In step two we developed a relationship between forest canopy and the reduction in accumulation of SWE due to canopy interception. Snow interception is expressed as the reduction of snow water equivalent (SWE) in lodgepole pine and spruce/fir stands as compared to snow accumulation in openings. Snow water equivalent was measured at six canopy-covered and eight open sites on the experimental forest since 1993. Since 1994 daily SWE has been recorded from two snow pillows on the experimental forest, one in the open and one under a forest canopy. Forest canopy has been measured and comparisons made between canopy cover and SWE at Natural Resource Conservation Service snow courses in Montana since the early 1960s (Farnes 1971). The effect of a logging altered forest canopy on SWE in Montana was studied by Hardy and Hansen-Bristow in 1990. After the 1988 fires in Yellowstone National Park, additional measurements were made in burned and unburned forest stands and compared to forest canopy (Farnes 1989; Farnes and Hartman 1989). Canopy cover and SWE data for stands with varying densities of canopy cover on the experimental forest were combined with data from these other studies (Hardy and Hansen-Bristow 1990; Skidmore et al. 1994 Moore 1997; Moore and McCaughey 1997). Measurements were made of canopy coverage using a

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photocanopyometer (Codd, 1959) that yielded a correlation ($R^2$ = 0.62) with snow interception.

In step three, data from TCEF and other studies (Farnes 1989; Farnes and Hartman 1989; Hardy and Hansen-Bristow 1990; Moore 1997; Moore and McCaughey 1997; Skidmore et al. 1994) were used to develop a relationship between percent forest canopy and habitat cover type (HCT) based on Despain, 1990. Habitat cover type classification is a method of classifying plant communities that result from a continuous successional process. The lower the HCT number designation the younger the stand. For example, an LP0 HCT represents a recently burned forest where lodgepole pine is expected to colonize the site or has done so already. An LP3 HCT is a mature stand containing extensive lodgepole pine mortality and high amounts of large and small seedlings and saplings of Engelmann spruce and subalpine fir. The species designation for a particular habitat cover type depends on the species that dominates a successional stage. The habitat type for a fire generated stand was combined with stand age, as determined by fire history, to obtain a numerical habitat cover type index value which more accurately reflects the successional stage of the stand. For example, a recently burned lodgepole pine stand is classified as an LP0. An LP1 is a mature forest and may be from 50 to 150 years old depending on site growing conditions. An LP3 is an overmature stand, generally older than 300 years with many dead and dying trees and is at climax. Likewise, an SF1 is a mature spruce/fir stand approximately 150 to 200 years old and an SF2.5 stand is near climax and approximately 400 to 500 years old. The age of mature stands was assumed to be 100 for lodgepole pine and 200 for spruce/fir stands on the experimental forest. Therefore, the HCT for a lodgepole pine stand is computed by dividing the age by 100 (150-year-old stand = LP1.5 HCT) and the HCT for a spruce/fir stand is the stand age divided by 200.

Data from steps one, two and three were combined in step four to quantify the reduction in SWE due to canopy interception and HCT index for lodgepole pine and spruce/fir stands. Habitat cover type and precipitation throughfall data from TCEF and other studies (Arthur and Fahey 1993; Fahey et al. 1988; Wilm and Niederhof 1941) were used in this process.

Average annual runoff was calculated in step five for each 5-centimeter precipitation increment which had been measured and delineated for the precipitation gradient of the experimental forest. Runoff from watersheds adjacent to the experimental forest (Farnes 1971, 1978; Farnes and Hartman 1989) was used to estimate past runoff for the experimental forest. The maximum and minimum annual runoff was computed for each precipitation zone assuming no forest canopy cover or complete canopy coverage. The canopy interception reduction in SWE and rain throughfall for each HCT was then used to calculate runoff for each habitat cover type in all precipitation zones. For example, the reduction in SWE and April - June precipitation was used to compute the runoff for the 900 mm (maximum) precipitation zone within a lodgepole pine HCT (Table 2). Average annual runoff for each precipitation zone and lodgepole pine HCT was then computed (Table 3) from values obtained from Table 2. Although changes in snowfall totals may have occurred over time, the reconstruction of the past 400+ years was based on the recent 30-year average period (1961 to 1990).

In the final step, we estimated average annual runoff from each fire-generated stand using habitat cover type before and after each fire. An HCT index value was assigned for each stand immediately prior to a fire. The stand was then reassigned a lower index value for the year after the fire, reflecting the stand's new open canopy condition. Net precipitation accumulation for each HCT and precipitation zone was estimated by taking the total precipitation input and estimating the reduction due to canopy interception of snow (SWE) and April to June rain. Average annual runoff was computed for all HCT stands and open areas based on precipitation zone and accumulated to obtain average annual runoff for the entire watershed for the year before and after each fire.

RESULTS AND DISCUSSION

Average annual runoff, the amount of precipitation falling as snow (April 1 SWE) and the amount falling as rain (April - June) increased at different rates as the average annual precipitation increased (Figure 1). Runoff is a function of precipitation received and the amount remaining after vegetation use, soil and groundwater recharge, evaporation and sublimation losses. Vegetation significantly affects soil and groundwater recharge and subsequent runoff. From the soil surface to a depth of 1.2 m, clearcuts or openings retain the highest percentage of soil moisture and mature stands the lowest (Newman and Schmidt 1980). Evaporation losses can be considerable in warm dry years. Sublimation is a function of the area in the forest, the age and species structure of the forest canopy, and the season in which precipitation occurs. April 1 SWE gives the greatest contribution to annual runoff because of saturated soils and minimal vegetation water use at the time of snowmelt. Average annual precipitation was positively correlated to elevation on TCEF.

Regression coefficients of percent canopy cover and SWE calculated as a percent of an open condition were not significantly different and were combined (Figure 2). The SWE showed a linear relationship and had a minimum accumulation of 69 percent of that measured in adjacent open areas in lodgepole pine and spruce/fir stands with 70 percent canopy cover.

Canopy cover increases quickly as lodgepole pine and spruce/fir stands approached maturity (HCT of 1 to 1.5) and decreased slowly as stands advanced into late successional stages (Figure 3). Mortality due to age, disease, windthrow and insects create gaps in late successional stands allowing increased amounts of snow and rain to reach the forest floor. Spruce/fir stands had a greater canopy coverage than lodgepole pine stands throughout all successional stages because of their denser foliage and shade tolerance characteristics, enabling multi-structured stands to develop.

Table 2. Calculations of the runoff for a lodgepole pine habitat cover type (HCT) for a 900 mm precipitation zone.

Precipitation zone 900 mm   Annual runoff 378 mm
April 1 SWE = 338 mm   Runoff ÷ precipitation 42 %
April - June precipitation 246 mm

| HCT LP | SWE reduction[1] | Precipitation reduction[2] | Total reduction[3] | Net precipitation[4] | Runoff[5] mm |
|---|---|---|---|---|---|
| .0 | 0 | 0 | 0 | 900 | 378 |
| .1 | 7 | 7 | 14 | 886 | 372 |
| .2 | 16 | 17 | 33 | 867 | 364 |
| .3 | 24 | 25 | 49 | 851 | 357 |
| .4 | 30 | 33 | 63 | 837 | 352 |
| .5 | 37 | 41 | 78 | 822 | 345 |
| .6 | 44 | 49 | 93 | 807 | 339 |
| .7 | 49 | 58 | 107 | 793 | 333 |
| .8 | 55 | 65 | 120 | 780 | 328 |
| .9 | 61 | 69 | 130 | 770 | 323 |
| 1.0 | 65 | 71 | 136 | 764 | 321 |
| 1.1 | 69 | 71 | 140 | 760 | 319 |
| 1.2 | 72 | 71 | 143 | 757 | 318 |
| 1.3 | 75 | 71 | 146 | 754 | 317 |
| 1.4 | 77 | 70 | 147 | 753 | 316 |
| 1.5 | 78 | 69 | 147 | 753 | 316 |
| 1.6 | 78 | 69 | 147 | 753 | 316 |
| 1.7 | 78 | 68 | 146 | 754 | 317 |
| 1.8 | 78 | 66 | 144 | 756 | 318 |
| 1.9 | 77 | 65 | 142 | 758 | 318 |
| 2.0 | 77 | 64 | 141 | 759 | 319 |
| 2.1 | 76 | 64 | 140 | 760 | 319 |
| 2.2 | 75 | 63 | 138 | 762 | 320 |
| 2.3 | 74 | 62 | 136 | 764 | 321 |
| 2.4 | 73 | 60 | 133 | 767 | 322 |
| 2.5 | 72 | 59 | 131 | 769 | 323 |
| 2.6 | 71 | 59 | 130 | 770 | 323 |
| 2.7 | 69 | 58 | 127 | 773 | 325 |
| 2.8 | 67 | 57 | 124 | 776 | 326 |
| 2.9 | 65 | 55 | 120 | 780 | 328 |
| 3.0 | 63 | 54 | 117 | 783 | 329 |

[1]338 - (% open x 338)   [4]Precipitation zone minus total reduction
[2]246 - (% open x 246)   [5]Net precipitation times 0.42
[3]Sum SWE and precipitation reduction

The amount of snow (SWE) and rain (April - June precipitation) that reached the forest floor decreased sharply as lodgepole pine and spruce/fir stands approached maturity (Figures 4 and 5). Precipitation throughfall and SWE remained constant for a short period after stands matured and then increased slowly as stands approached late successional stages. A higher percentage of snow reaches the forest floor under lodgepole pine than under spruce/fir stands because of the dense foliage characteristics of spruce and fir (Figures 4 and 5). Precipitation throughfall as rain is nearly equal for lodgepole pine and spruce/fir stands.

Table 3. Average annual runoff for lodgepole pine habitat cover types (HCT) and average annual precipitation zones.

| HCT | Average annual precipitation zones, mm | | | | | | | | | |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| LP | 600 | 650 | 700 | 750 | 800 | 850 | 900 | 950 | 1000 | 1050 |
| | | | | Runoff | (mm) | | | | | |
| .0 | 126 | 169 | 210 | 255 | 296 | 340 | 378 | 418 | 460 | 504 |
| .1 | 124 | 166 | 206 | 251 | 291 | 334 | 372 | 411 | 453 | 496 |
| .2 | 121 | 162 | 202 | 245 | 285 | 328 | 364 | 403 | 444 | 486 |
| .3 | 118 | 159 | 198 | 240 | 280 | 322 | 357 | 396 | 436 | 478 |
| .4 | 116 | 156 | 194 | 236 | 275 | 316 | 352 | 389 | 428 | 470 |
| .5 | 114 | 153 | 190 | 232 | 270 | 310 | 345 | 382 | 421 | 462 |
| .6 | 111 | 150 | 187 | 227 | 264 | 304 | 339 | 376 | 414 | 454 |
| .7 | 109 | 147 | 183 | 223 | 259 | 299 | 333 | 369 | 407 | 446 |
| .8 | 107 | 144 | 180 | 219 | 255 | 294 | 328 | 363 | 400 | 440 |
| .9 | 105 | 142 | 177 | 216 | 252 | 290 | 323 | 359 | 396 | 434 |
| 1.0 | 104 | 141 | 176 | 214 | 249 | 288 | 321 | 356 | 392 | 431 |
| 1.1 | 104 | 140 | 175 | 213 | 248 | 286 | 319 | 354 | 390 | 429 |
| 1.2 | 103 | 139 | 174 | 212 | 247 | 285 | 318 | 352 | 389 | 427 |
| 1.3 | 103 | 139 | 173 | 211 | 246 | 284 | 317 | 351 | 387 | 425 |
| 1.4 | 103 | 139 | 173 | 211 | 246 | 284 | 316 | 351 | 387 | 424 |
| 1.5 | 103 | 139 | 173 | 211 | 246 | 284 | 316 | 351 | 387 | 425 |
| 1.6 | 103 | 139 | 173 | 211 | 246 | 284 | 316 | 351 | 387 | 425 |
| 1.7 | 103 | 139 | 174 | 212 | 247 | 284 | 317 | 352 | 388 | 425 |
| 1.8 | 103 | 139 | 174 | 212 | 247 | 284 | 318 | 352 | 388 | 427 |
| 1.9 | 104 | 140 | 175 | 212 | 248 | 285 | 318 | 352 | 389 | 427 |
| 2.0 | 104 | 140 | 175 | 214 | 248 | 286 | 319 | 353 | 390 | 428 |
| 2.1 | 104 | 140 | 175 | 214 | 248 | 286 | 319 | 354 | 391 | 428 |
| 2.2 | 104 | 140 | 176 | 214 | 249 | 287 | 320 | 355 | 391 | 430 |
| 2.3 | 105 | 141 | 176 | 215 | 250 | 288 | 321 | 356 | 392 | 431 |
| 2.4 | 105 | 142 | 177 | 216 | 251 | 289 | 322 | 357 | 394 | 432 |
| 2.5 | 105 | 142 | 177 | 216 | 252 | 290 | 323 | 358 | 395 | 433 |
| 2.6 | 105 | 142 | 178 | 217 | 252 | 290 | 323 | 359 | 395 | 433 |
| 2.7 | 106 | 143 | 178 | 218 | 253 | 292 | 325 | 360 | 397 | 435 |
| 2.8 | 106 | 144 | 179 | 218 | 254 | 293 | 326 | 362 | 398 | 437 |
| 2.9 | 107 | 144 | 180 | 219 | 256 | 294 | 328 | 363 | 400 | 439 |
| 3.0 | 108 | 145 | 181 | 220 | 256 | 295 | 329 | 364 | 402 | 440 |

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Average annual runoff was estimated at 12.48 X 10$^6$ m$^3$ when fires burned 51 percent of TCEF in 1581, producing the highest estimated average annual runoff during the past 400 years (Table 4 and Figure 6). The average annual runoff from 1581 to 1997 was estimated to be 11.68 X 10$^6$ m$^3$. If all timber from TCEF were removed, the annual runoff is estimated to be 13.24 X 10$^6$ m$^3$ in an average precipitation year, 21.19 X 10$^6$ m$^3$ in a wet year (160 percent of average based on data from gaged streams near TCEF) and 6.62 X 10$^6$ m$^3$ in a dry year (50% of average). The annual runoff was estimated at 11.23 X 10$^6$ m$^3$ in an average year, 17.97 X 10$^6$ m$^3$ in a wet year and 5.62 X 10$^6$ m$^3$ in a dry year if all stands on TCEF were mature lodgepole pine (HCT of 1). The 1997 estimate of average annual runoff (11.36 X 10$^6$ m$^3$) approaches the minimum yield value of 11.23 X 10$^6$ m$^3$ occurring under mature forest conditions (Figure 6).

Table 4.     Estimated annual runoff in cubic meters (m$^3$).

| Period | | m$^3$ |
|---|---|---|
| 1581-1997 | Average annual runoff = | 11.678 |
| 1961-1990 | Average annual runoff = | 11.458 |
| 1997 | Average annual runoff = | 11.360 |
| 1581-1997 | Maximum average annual runoff (1581) = | 12.485 |
| 1581-1997 | Minimum average annual runoff (1873) = | 11.247 |
| | Average annual runoff with all forest burned = | 13.241 |
| | Average annual runoff with 91% mature forest = | 11.230 |
| | Maximum annual runoff, no forest, wet year = | 21.186 |
| | Minimum annual runoff, 91% mature forest, dry year = | 5.615 |

SUMMARY

Fire has played a significant role in determining the average annual runoff patterns for Tenderfoot Creek Experimental Forest over the past 400+ years and throughout the North American west. Prior to fire suppression, when average annual runoff approached a minimum level in a mature forest, fires removed large portions of the forest canopy, resulting in increased runoff (Figure 6). Fire suppression and succession over the last 90 years has allowed the forested areas to remain in a mature stage, resulting in water yields that are now approaching the minimum estimated level. Continued fire suppression will create a fuel buildups that could result in catastrophic fires. The effects of a major fire event would severely impact stream channels, fisheries, wildlife and recreation. This study shows that it is possible to estimate the historic variability in runoff in lodgepole pine and spruce/fir forests using past fire patterns, average annual precipitation, April SWE, April - June precipitation and habitat cover type. We feel that this approach to estimate historic runoff patterns can be used in other forest types if precipitation throughfall and other input variables are known. Management strategies can be applied that create a mixture of successional stages which reduce fire potentials, and thereby influence water yields.

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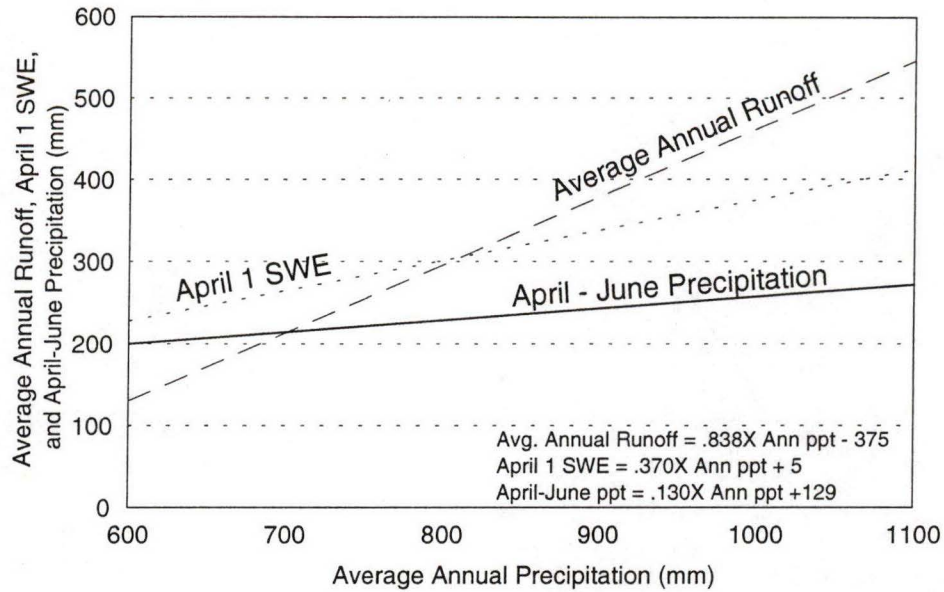
Figure 1.   Relationship of average annual runoff, April 1 snow water equivalent (SWE) and April - June precipitation in open canopy areas to average annual precipitation.
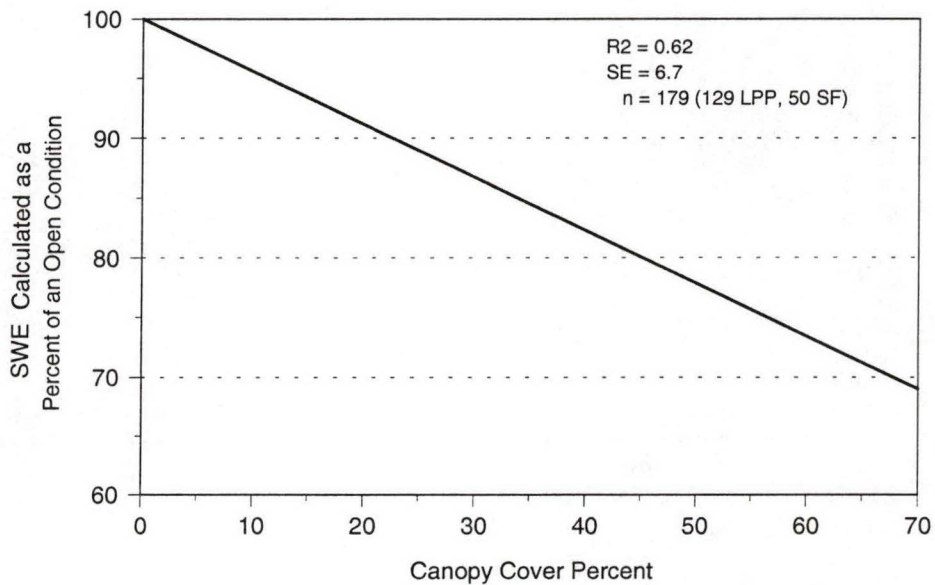


Figure 2.   Snow water equivalent calculated as a percent of an open condition compared to percent canopy cover for lodgepole pine and spruce/fir stands in and near the Tenderfoot Creek Experimental Forest. Canopy cover is measured with a photocanopyometer with a 30° cone.

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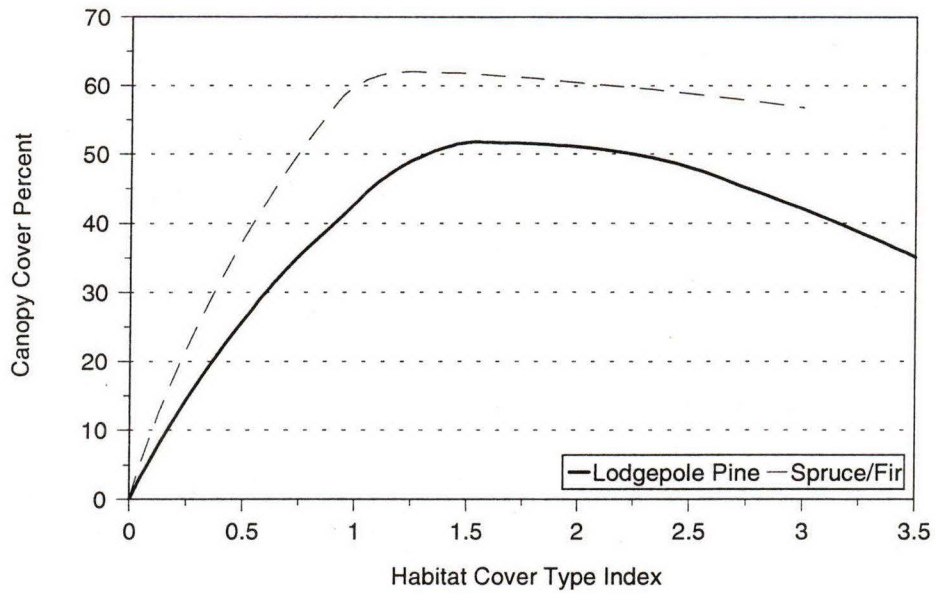
Figure 3. Relationship between canopy cover measured with a photocanopyometer and the habitat cover type index for lodgepole pine and spruce/fir stands.
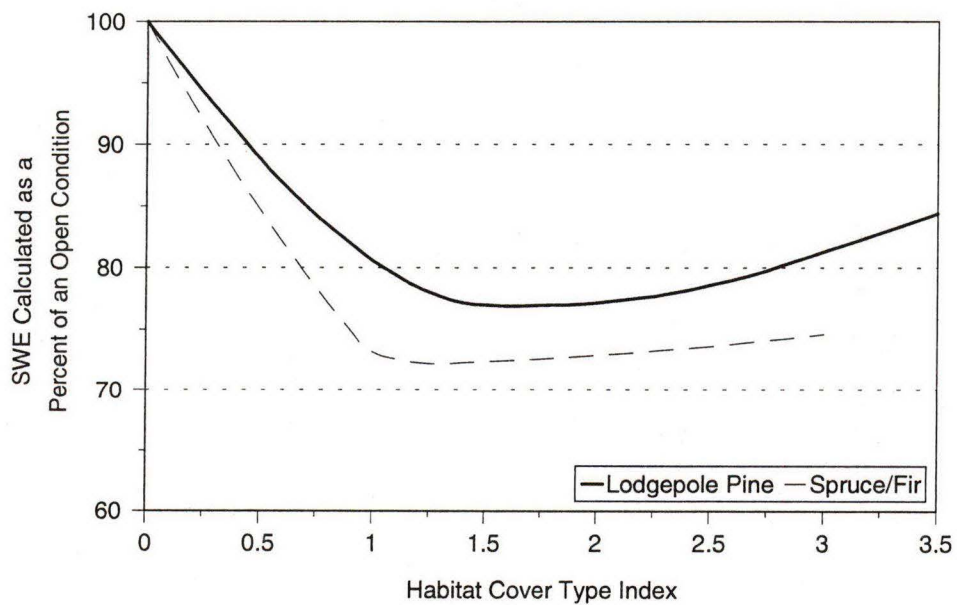


Figure 4. Relationship between snow water equivalent (SWE) calculated as a percent of an open condition and habitat cover type under lodgepole pine and spruce/fir stands.

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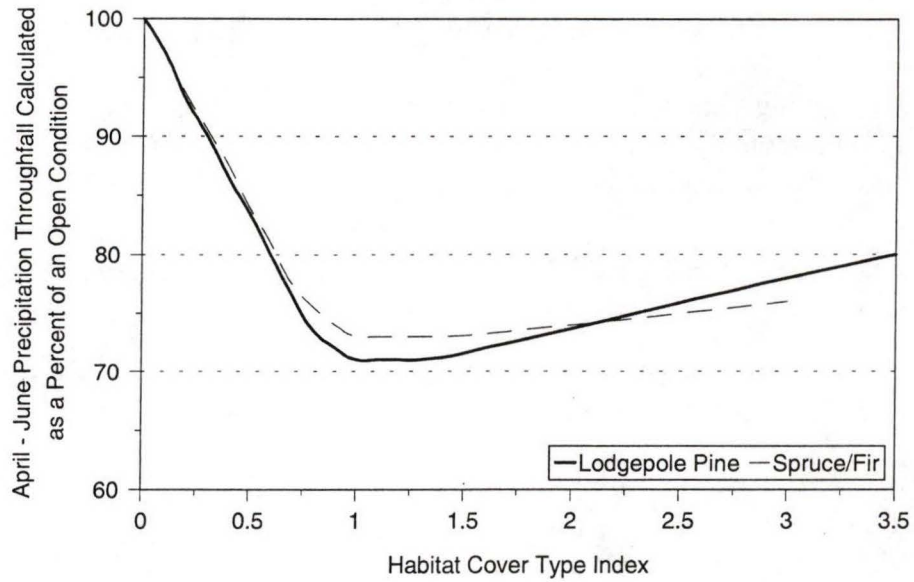
Figure 5.    Relationship between April - June precipitation (rain) throughfall calculated as a percent of an open condition and habitat cover type index under lodgepole pine and spruce/fir stands.
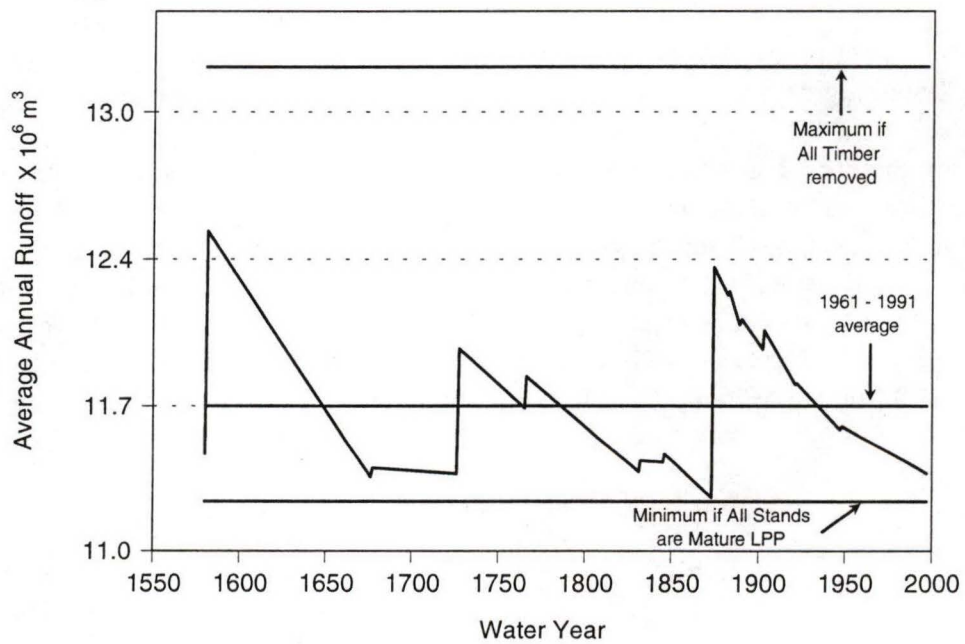


Figure 6.    Average annual runoff based on fire history data and canopy cover/precipitation/runoff relationships under the 1961-1990 average precipitation regime.

## APPENDIX II. HISTORIC MONTHLY TEMPERATURES FOR ONION PARK, TENDERFOOT CREEK EXPERIMENTAL FOREST

The following stations were used to estimate historic average maximum (TMax) and minimum (TMin) monthly temperature for the Onion Park site (7,410 ft) on TCEF. Daily temperatures at this site have been recorded since the 1992 water year (WY).

### Name, Type, Elevation and Period of Record for Temperature Station

| Station | Type | Elev. Ft. | Period of Record (WY) |
|---|---|---|---|
| Deadman Creek | SNOTEL | 6,450 | 1992-present |
| Kings Hill | CLIM | 7,310 | 1949-1965 |
| Neihart 8NNW | CLIM | 5,230 | 1968-present |
| Spur Park | SNOTEL | 8,100 | 1983-present |
| White Sulphur Springs | CLIM | 5,160 | 1912-1978 |
| White Sulphur Springs 2 | CLIM | 5,200 | 1979-present |

SNOTEL = Snow Survey Telemetry station maintained and operated by NRCS.
CLIM = Climatological station operated by NWS and cooperative observers.

Temperature records have been collected at the Stringer Creek site (6,550 ft) on Tenderfoot Creek Experimental Forest starting in the 1996 water year. Not enough data has been collected yet to develop a historic data set, but the following equation has been developed using 1996-1998 data ($R^2 = .927$) to estimate average temperature (TAvg). TMax and TMin data for Stringer Creek has not been analyzed. Stringer Creek TAvg = 1.01 x Onion Park TAvg + 0.5. Temperatures are in degrees Fahrenheit correlations, and estimating equations used to determine historic temperatures for Onion Park are on file at the Forestry Sciences Laboratory in Bozeman, Montana.

# Tenderfoot Creek Experimental Forest
## Average Maximum and Minimum Monthly Temperatures for Onion Park, °F

### Average TMAX

| WY | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Annual Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1961 | 44 | 31 | 26 | 27 | 32 | 34 | 36 | 50 | 65 | 68 | 70 | 48 | 44 |
| 1962 | 43 | 29 | 19 | 19 | 21 | 29 | 46 | 48 | 58 | 62 | 63 | 53 | 41 |
| 1963 | 48 | 36 | 29 | 17 | 32 | 32 | 39 | 51 | 56 | 67 | 67 | 62 | 45 |
| 1964 | 50 | 32 | 22 | 22 | 26 | 26 | 39 | 48 | 55 | 70 | 60 | 50 | 42 |
| 1965 | 50 | 29 | 21 | 26 | 24 | 21 | 39 | 44 | 55 | 63 | 60 | 39 | 39 |
| 1966 | 50 | 32 | 27 | 21 | 24 | 32 | 38 | 53 | 55 | 68 | 63 | 60 | 44 |
| 1967 | 43 | 31 | 24 | 24 | 27 | 26 | 32 | 48 | 53 | 65 | 67 | 60 | 42 |
| 1968 | 43 | 31 | 17 | 21 | 27 | 36 | 38 | 44 | 53 | 65 | 60 | 51 | 41 |
| 1969 | 43 | 29 | 19 | 10 | 21 | 26 | 44 | 53 | 53 | 63 | 68 | 58 | 41 |
| 1970 | 32 | 36 | 27 | 19 | 31 | 26 | 31 | 50 | 60 | 67 | 68 | 50 | 41 |
| 1971 | 39 | 31 | 22 | 19 | 26 | 27 | 39 | 51 | 55 | 63 | 70 | 50 | 41 |
| 1972 | 39 | 31 | 19 | 15 | 27 | 38 | 39 | 48 | 60 | 60 | 65 | 51 | 41 |
| 1973 | 41 | 29 | 15 | 19 | 26 | 32 | 36 | 50 | 58 | 67 | 65 | 51 | 41 |
| 1974 | 43 | 24 | 26 | 17 | 27 | 29 | 43 | 43 | 63 | 68 | 58 | 55 | 41 |
| 1975 | 50 | 32 | 26 | 19 | 21 | 24 | 29 | 44 | 53 | 65 | 60 | 55 | 40 |
| 1976 | 41 | 27 | 27 | 24 | 27 | 29 | 41 | 53 | 55 | 67 | 62 | 58 | 43 |
| 1977 | 43 | 32 | 26 | 17 | 31 | 29 | 48 | 48 | 62 | 65 | 63 | 56 | 43 |
| 1978 | 46 | 29 | 22 | 19 | 22 | 36 | 41 | 48 | 60 | 63 | 63 | 55 | 42 |
| 1979 | 48 | 22 | 15 | 7 | 22 | 32 | 38 | 50 | 60 | 65 | 65 | 63 | 41 |
| 1980 | 48 | 29 | 31 | 17 | 26 | 29 | 48 | 53 | 58 | 65 | 60 | 55 | 43 |
| 1981 | 46 | 32 | 29 | 34 | 27 | 36 | 39 | 44 | 53 | 63 | 70 | 58 | 44 |
| 1982 | 41 | 36 | 22 | 17 | 21 | 29 | 36 | 46 | 55 | 63 | 67 | 53 | 41 |
| 1983 | 41 | 27 | 22 | 29 | 27 | 34 | 43 | 48 | 56 | 65 | 72 | 53 | 43 |
| 1984 | 43 | 27 | 14 | 22 | 31 | 32 | 44 | 50 | 58 | 70 | 72 | 50 | 43 |
| 1985 | 32 | 27 | 19 | 22 | 17 | 34 | 44 | 56 | 60 | 74 | 62 | 44 | 41 |
| 1986 | 38 | 17 | 21 | 27 | 24 | 41 | 44 | 51 | 67 | 62 | 68 | 44 | 42 |
| 1987 | 48 | 26 | 24 | 22 | 31 | 32 | 53 | 56 | 63 | 65 | 62 | 62 | 45 |
| 1988 | 48 | 34 | 21 | 17 | 24 | 31 | 46 | 56 | 68 | 72 | 68 | 55 | 45 |
| 1989 | 50 | 26 | 22 | 21 | 15 | 31 | 41 | 50 | 60 | 72 | 63 | 56 | 42 |
| 1990 | 41 | 27 | 21 | 22 | 22 | 36 | 46 | 50 | 58 | 68 | 68 | 67 | 44 |
| 1991 | 39 | 31 | 12 | 17 | 32 | 31 | 39 | 48 | 58 | 68 | 72 | 58 | 42 |
| 1992 | 41 | 27 | 27 | 27 | 36 | 43 | 46 | 53 | 60 | 58 | 63 | 53 | 45 |
| 1993 | 44 | 26 | 21 | 21 | 26 | 36 | 41 | 55 | 51 | 55 | 58 | 51 | 40 |
| 1994 | 43 | 24 | 24 | 26 | 21 | 36 | 44 | 54 | 60 | 68 | 70 | 63 | 44 |
| 1995 | 40 | 25 | 24 | 25 | 28 | 31 | 37 | 49 | 56 | 64 | 66 | 53 | 41 |
| 1996 | 37 | 31 | 24 | 20 | 24 | 28 | 46 | 48 | 62 | 73 | 68 | 52 | 43 |
| 1997 | 40 | 28 | 21 | 22 | 27 | 33 | 38 | 52 | 57 | 64 | 65 | 61 | 42 |
| 1998 | 39 | 32 | 26 | 24 | 32 | 34 | 43 | 52 | 50 | 72 | 71 | 64 | 45 |
| 1961-90 average: | 44 | 29 | 23 | 20 | 25 | 31 | 41 | 49 | 58 | 66 | 65 | 54 | 42 |

### Average TMIN

| WY | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Annual Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1961 | 22 | 13 | 6 | 10 | 13 | 13 | 17 | 27 | 38 | 42 | 42 | 24 | 22 |
| 1962 | 17 | 8 | 3 | -3 | 3 | 6 | 19 | 27 | 33 | 36 | 34 | 27 | 18 |
| 1963 | 24 | 15 | 11 | -12 | 11 | 11 | 17 | 26 | 34 | 36 | 36 | 34 | 20 |
| 1964 | 26 | 15 | 3 | 6 | 6 | 4 | 17 | 29 | 34 | 42 | 34 | 27 | 20 |
| 1965 | 22 | 11 | 3 | 11 | 4 | -3 | 22 | 24 | 33 | 38 | 38 | 22 | 19 |
| 1966 | 26 | 15 | 10 | 3 | 4 | 11 | 15 | 27 | 33 | 40 | 34 | 34 | 21 |
| 1967 | 22 | 11 | 8 | 8 | 10 | 6 | 13 | 26 | 34 | 38 | 36 | 33 | 20 |
| 1968 | 26 | 11 | -3 | 1 | 11 | 17 | 15 | 24 | 33 | 38 | 34 | 29 | 20 |
| 1969 | 22 | 13 | -3 | -8 | 1 | 3 | 22 | 27 | 31 | 38 | 36 | 33 | 18 |
| 1970 | 15 | 15 | 10 | 3 | 11 | 8 | 15 | 27 | 36 | 40 | 38 | 26 | 20 |
| 1971 | 17 | 10 | 6 | 4 | 10 | 10 | 19 | 27 | 33 | 34 | 42 | 26 | 20 |
| 1972 | 19 | 13 | -1 | -5 | 10 | 17 | 17 | 26 | 36 | 36 | 38 | 27 | 19 |
| 1973 | 17 | 13 | -1 | -1 | 3 | 13 | 17 | 24 | 34 | 38 | 38 | 29 | 19 |
| 1974 | 24 | 10 | 11 | -1 | 13 | 11 | 22 | 24 | 36 | 40 | 34 | 26 | 21 |
| 1975 | 22 | 17 | 10 | 3 | -1 | 6 | 11 | 26 | 33 | 43 | 34 | 26 | 19 |
| 1976 | 22 | 11 | 11 | 6 | 11 | 6 | 19 | 29 | 33 | 40 | 38 | 29 | 21 |
| 1977 | 19 | 11 | 10 | -1 | 13 | 11 | 19 | 27 | 38 | 38 | 36 | 29 | 21 |
| 1978 | 22 | 10 | 3 | -3 | 3 | 13 | 22 | 26 | 29 | 38 | 36 | 31 | 19 |
| 1979 | 22 | 4 | 1 | -10 | 6 | 15 | 22 | 27 | 34 | 38 | 38 | 33 | 19 |
| 1980 | 27 | 10 | 13 | 1 | 13 | 11 | 26 | 31 | 36 | 38 | 34 | 34 | 23 |
| 1981 | 24 | 17 | 8 | 13 | 11 | 15 | 22 | 27 | 34 | 36 | 38 | 33 | 23 |
| 1982 | 22 | 19 | 10 | -1 | 6 | 15 | 19 | 26 | 36 | 42 | 40 | 31 | 22 |
| 1983 | 22 | 10 | 4 | 13 | 15 | 13 | 13 | 24 | 31 | 40 | 43 | 27 | 21 |
| 1984 | 24 | 13 | -10 | 6 | 10 | 13 | 15 | 22 | 31 | 42 | 43 | 26 | 20 |
| 1985 | 17 | 11 | 3 | 3 | -1 | 6 | 19 | 29 | 33 | 43 | 34 | 24 | 18 |
| 1986 | 17 | -1 | 4 | 13 | 4 | 17 | 17 | 24 | 38 | 34 | 40 | 27 | 20 |
| 1987 | 27 | 8 | 10 | 6 | 11 | 11 | 22 | 31 | 36 | 38 | 33 | 34 | 22 |
| 1988 | 24 | 19 | 6 | 1 | 6 | 10 | 19 | 27 | 40 | 40 | 38 | 29 | 22 |
| 1989 | 27 | 11 | 8 | 6 | -6 | 8 | 17 | 26 | 33 | 42 | 38 | 31 | 20 |
| 1990 | 24 | 13 | 6 | 8 | 3 | 10 | 19 | 24 | 33 | 40 | 42 | 38 | 22 |
| 1991 | 20 | 17 | -6 | 3 | 15 | 8 | 17 | 24 | 33 | 38 | 43 | 36 | 21 |
| 1992 | 22 | 13 | 15 | 13 | 20 | 22 | 24 | 31 | 40 | 38 | 40 | 33 | 26 |
| 1993 | 27 | 15 | 4 | 6 | 6 | 17 | 20 | 31 | 33 | 36 | 38 | 31 | 22 |
| 1994 | 26 | 8 | 12 | 14 | 2 | 15 | 22 | 32 | 38 | 43 | 45 | 37 | 25 |
| 1995 | 25 | 10 | 12 | 11 | 10 | 12 | 17 | 27 | 35 | 42 | 41 | 34 | 23 |
| 1996 | 23 | 17 | 10 | 3 | 6 | 8 | 22 | 27 | 37 | 43 | 42 | 32 | 23 |
| 1997 | 23 | 15 | 9 | 7 | 10 | 12 | 14 | 28 | 37 | 41 | 42 | 37 | 23 |
| 1998 | 24 | 15 | 9 | 9 | 13 | 12 | 22 | 30 | 32 | 46 | 44 | 40 | 25 |
| 1961-90 average: | 22 | 12 | 5 | 3 | 7 | 10 | 18 | 26 | 34 | 39 | 37 | 29 | 20 |

### 1961-90 Average Monthly Temperatures (TAVG)

| Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 33 | 21 | 14 | 12 | 16 | 21 | 30 | 38 | 46 | 53 | 51 | 42 | 31 |

Note: 1983-1993 estimated from Spur Park SNOTEL site. Prior years estimated from a combination of stations. TAVG = (TMAX + TMIN) / 2

# APPENDIX III.  HISTORIC SNOW WATER EQUIVALENT ON TENDERFOOT CREEK EXPERIMENTAL FOREST

Snow water equivalents (SWE) have been measured at eight open and six closed-canopy snow courses on Tenderfoot Creek Experimental Forest starting in the 1993 water year (WY). Three snow pillows have been installed on TCEF.  At Onion Park, one snow pillow is in the open with no canopy and a second is under the forest canopy; both were installed in 1993.  At Stringer Creek, one snow pillow was installed in 1995 in the open.  First-of-the-month SWE for January through May has been estimated for the snow courses using snow pillow data from Onion Park, Stringer Creek, Deadman Creek and Spur Park.

Correlations and procedures used to estimate the average of eight snow courses on Tenderfoot Creek Experimental Forest for 1961-1992 is on file at the Forestry Sciences Laboratory in Bozeman, Montana.

Correlations between individual stations and the average of eight sites and between individual adjacent stations is shown in this appendix.

## Name, Elevation and Period of Record for Snow Water Equivalent Stations

| Snow Course | Elevation (ft) | Period of Record (WY) |
|---|---|---|
| *Bubbling Springs[1] | 7,430 | 1993-present |
| *County Line[1] | 7,810 | 1993-present |
| *Dry Park | 7,420 | 1993-present |
| *Farnes Meadow[1] | 7,400 | 1993-present |
| *Lonesome Creek[1] | 6,970 | 1993-present |
| *Onion Park[1] | 7,410 | 1993-present |
| Onion Park Open Pillow | 7,410 | 1994-present |
| Onion Park Canopy Pillow | 7,410 | 1994-present |
| *Stringer Creek | 6,550 | 1993-present |
| Stringer Creek Open Pillow | 6,550 | 1996-present |
| *Sun Creek[1] | 7,040 | 1993-present |
| Deadman Creek Pillow | 6,450 | 1961-present |
| Kings Hill | 7,500 | 1934-present |
| Spur Park Pillow | 8,100 | 1961-present |

*Eight original open snow courses, average elevation 7,254 ft. Average elevation of TCEF is 7,236 ft and average elevation of Deadman Creek and Spur Park is 7,275 ft.

[1]Locations also having snow courses in forest canopy.

# Tenderfoot Creek Experimental Forest
## First-of-the-month SWE*, inches

| Water Year | Jan 1 | Feb 1 | Mar 1 | Apr 1 | May 1 |
|---|---|---|---|---|---|
| 1961 | 3.8 | 4.2 | 5.8 | 8.9 | 12.7 |
| 1962 | 6.0 | 8.8 | 10.8 | 13.8 | 9.7 |
| 1963 | 3.2 | 7.7 | 9.0 | 11.0 | 13.0 |
| 1964 | 3.7 | 8.6 | 12.3 | 16.6 | 17.7 |
| 1965 | 6.4 | 12.4 | 15.3 | 17.7 | 18.9 |
| 1966 | 3.1 | 6.7 | 10.1 | 10.1 | 11.0 |
| 1967 | 5.7 | 12.1 | 16.4 | 19.9 | 22.9 |
| 1968 | 8.8 | 10.9 | 13.3 | 14.8 | 13.8 |
| 1969 | 5.1 | 10.3 | 11.6 | 12.4 | 7.4 |
| 1970 | 6.6 | 12.4 | 15.0 | 19.4 | 22.8 |
| 1971 | 5.7 | 11.7 | 14.3 | 18.3 | 18.6 |
| 1972 | 9.7 | 15.6 | 20.3 | 21.5 | 19.9 |
| 1967 | 3.9 | 5.6 | 6.6 | 8.1 | 9.6 |
| 1974 | 7.4 | 11.1 | 14.4 | 17.1 | 14.9 |
| 1975 | 5.6 | 10.5 | 12.2 | 15.6 | 18.3 |
| 1976 | 7.8 | 10.8 | 13.6 | 14.5 | 14.8 |
| 1977 | 5.8 | 11.1 | 14.6 | 18.7 | 16.0 |
| 1978 | 9.7 | 12.7 | 15.0 | 16.0 | 13.8 |
| 1979 | 6.1 | 10.0 | 12.1 | 13.1 | 12.0 |
| 1980 | 5.5 | 9.9 | 12.4 | 16.5 | 14.8 |
| 1981 | 5.1 | 9.1 | 11.3 | 14.5 | 13.7 |
| 1982 | 8.1 | 14.4 | 18.1 | 20.9 | 20.2 |
| 1983 | 4.0 | 5.7 | 7.1 | 8.4 | 9.1 |
| 1984 | 6.6 | 9.7 | 12.4 | 15.8 | 14.3 |
| 1985 | 6.4 | 9.8 | 12.1 | 15.4 | 14.0 |
| 1986 | 7.2 | 10.2 | 13.1 | 13.5 | 12.1 |
| 1987 | 3.9 | 6.2 | 7.8 | 11.1 | 7.9 |
| 1988 | 7.9 | 12.0 | 14.6 | 16.7 | 13.7 |
| 1989 | 4.0 | 8.5 | 10.1 | 13.6 | 13.4 |
| 1990 | 7.0 | 10.7 | 12.4 | 15.0 | 11.1 |
| 1991 | 6.3 | 10.1 | 11.5 | 15.0 | 16.5 |
| 1992 | 5.3 | 7.1 | 8.2 | 8.6 | 7.0 |
| 1993 | 7.0 | 10.5 | 11.9 | 13.3 | 15.5 |
| 1994 | 8.8 | 13.3 | 14.5 | 16.6 | 14.7 |
| 1995 | 7.0 | 9.6 | 10.5 | 14.6 | 18.4 |
| 1996 | 5.9 | 8.9 | 11.2 | 15.6 | 16.0 |
| 1997 | 10.7 | 13.5 | 16.8 | 18.7 | 19.6 |
| 1998 | 4.4 | 7.8 | 8.7 | 11.4 | 9.8 |
| 1961-90 average: | 6.0 | 10.0 | 12.5 | 15.0 | 14.4 |
| 1961-98 min: | 3.1 | 4.2 | 5.8 | 8.1 | 7.0 |
| 1961-98 max: | 10.7 | 15.6 | 20.3 | 21.5 | 22.9 |

* Average, minimum and maximum first-of-the-month SWE values averaged from Bubbling Springs, County Line, Dry Park, Farnes Meadow, Lonesome Creek, Onion Park, Stringer Creek and Sun Creek snow courses. 1961-1992 values estimated from Spur Park and Deadman Creek snow pillows.

**Estimated 1961-1990 Average January 1 Through May 1 Snow Water Equivalent, Inches**

| | Station | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Date | Bubbling Springs | County Line | Dry Park | Farnes Meadow | Lonesome Creek | Onion Park | Stringer Creek | Sun Creek |
| Jan 1 | 6.5 | 7.4 | 6.9 | 6.6 | 5.1 | 6.2 | 4.0 | 5.5 |
| Feb 1 | 10.7 | 11.9 | 10.7 | 11.0 | 8.6 | 10.7 | 7.0 | 9.5 |
| Mar 1 | 13.3 | 14.7 | 13.1 | 13.8 | 10.8 | 13.5 | 8.9 | 12.0 |
| Apr 1 | 16.0 | 17.6 | 15.5 | 16.5 | 13.0 | 16.3 | 10.8 | 14.4 |
| May 1 | 15.3 | 16.9 | 14.9 | 15.8 | 12.5 | 15.6 | 10.3 | 13.9 |
| | Onion Park Open Pillow | Onion Park Canopy Pillow | Stringer Creek Pillow | | | | | |
| Jan 1 | 4.9 | 3.5 | 4.0 | | | | | |
| Feb 1 | 8.7 | 6.3 | 6.8 | | | | | |
| Mar 1 | 11.1 | 8.0 | 8.6 | | | | | |
| Apr 1 | 13.4 | 9.8 | 10.3 | | | | | |
| May 1 | 12.9 | 9.8 | 9.9 | | | | | |

## Tenderfoot Creek Experimental Forest
## Historic SWE for Snow Courses
First Month SWE, inches (based on data through 5/98)

|  |  | $R^2$ |
|---|---|---|
| Average 8* TCEF snow courses | = 0.93 x Average Spur Park Pillow and Deadman Creek Pillow - 0.9 | .98 |
| Bubbling Springs | = 1.05 x Average 8TCEF + 0.2 | .97 |
| County Line | = 1.13 x Average 8TCEF + 0.6 | .98 |
| Dry Park | = 0.96 x Average 8TCEF + 1.1 | .98 |
| Farnes Meadow | = 1.10 x Average 8TCEF ± 0 | .99 |
| Lonesome Creek | = 0.88 x Average 8TCEF - 0.2 | .99 |
| Onion Park | = 1.12 x Average 8TCEF - 0.5 | .99 |
| Onion Park Pillow | = 0.95 x Average 8TCEF - 0.8 | .99 |
| Stringer Creek | = 0.76 x Average 8TCEF - 0.6 | .89 |
| Stringer Creek Pillow | = 0.70 x Average 8TCEF - 0.2 | .90 |
| Sun Creek | = 0.99 x Average 8TCEF - 0.4 | .98 |

*Average of Bubbling Springs, County Line, Dry Park, Farnes Meadow, Lonesome Creek, Onion Park, Stringer Creek and Sun Creek snow courses.

## Tenderfoot Creek Experimental Forest
## Estimating Equations for Missing SWE for Snow Sites
First Month SWE, inches (based on data through 5/98)

|  |  | $R^2$ |
|---|---|---|
| Bubbling Springs | = 0.92 x County Line - 0.2 | .97 |
|  | = 1.09 x Dry Park - 1.0 | .98 |
|  | = 0.95 x Farnes Meadow + 0.3 | .95 |
|  | = 1.17 x Lonesome Creek + 0.5 | .95 |
|  | = 0.93 x Onion Park + 0.8 | .95 |
|  | = 1.10 x Onion Park Pillow + 1.0 | .98 |
| County Line | = 1.05 x Bubbling Springs +0.7 | .97 |
|  | = 1.16 x Dry Park = 0.6 | .98 |
|  | = 1.03 x Farnes Meadow + 0.6 | .99 |
|  | = 1.00 x Onion Park + 1.2 | .97 |
|  | = 1.18 x Onion Park Pillow + 1.6 | .99 |
| Dry Park | = 0.90 x Bubbling Springs + 1.2 | .98 |
|  | = 0.85 x County Line + 0.8 | .98 |
|  | = 0.87 x Farnes Meadow + 1.2 | .98 |
|  | = 0.86 x Onion Park + 1.6 | .98 |
|  | = 1.01 x Onion Park Pillow + 2.0 | .99 |
| Farnes Meadow | = 1.01 x Bubbling Springs + 0.3 | .95 |
|  | = 0.97 x County Line - 0.5 | .99 |
|  | = 1.12 x Dry Park - 1.1 | .98 |
|  | = 0.98 x Onion Park + 0.5 | .99 |
|  | = 1.14 x Onion Park Pillow + 1.0 | .99 |
| Lonesome Creek | = 0.82 x Bubbling Springs ± 0 | .95 |
|  | = 1.18 x Stringer Pillow + 0.8 | .94 |
|  | = 0.89 x Sun Creek + 0.3 | .98 |

Estimating Equations for SWE (continued)

| | | |
|---|---|---|
| Onion Park | = 1.03 x Bubbling Springs - 0.2 | .95 |
| | = 0.98 x County Line - 0.8 | .97 |
| | = 1.15 x Dry Park - 1.6 | .98 |
| | = 1.01 x Farnes Meadow - 0.4 | .99 |
| | = 1.16 x Onion Park Pillow + 0.6 | .99 |
| Onion Park Pillow | = 0.89 x Bubbling Springs - 0.8 | .98 |
| | = 0.84 x County Line - 1.2 | .99 |
| | = 0.98 x Dry Park - 1.8 | .99 |
| | = 0.86 x Farnes Meadow - 0.8 | .99 |
| Stringer Creek | = 0.80 x Lonesome Creek - 0.2 | .94 |
| | = 1.10 x Stringer Creek Pillow - 0.4 | .99 |
| Stringer Creek Pillow | = 0.80 x Lonesome Creek - 0.2 | .94 |
| | = 0.90 x Stringer Creek + 0.5 | .99 |
| | = 0.72 x Sun Creek ± 0 | .94 |
| Sun Creek | = 1.11 x Lonesome Creek - 0.2 | .98 |
| | = 1.32 x Stringer Creek Pillow + 0.6 | .94 |

## APPENDIX IV.  HISTORIC MONTHLY PRECIPITATION ON TENDERFOOT CREEK EXPERIMENTAL FOREST

Precipitation has been measured at eight storage gages since October 1992 (1993 WY). Two additional storage gages were installed more recently at Passionate Creek and Upper Stringer Creek.

Monthly data has been correlated between the ten data sites and the average of the eight original gages has been correlated with SNOTEL precipitation data from Deadman Creek and Spur Park.  Data and procedures used to estimate historic precipitation data is on file at the Forestry Sciences Laboratory at Bozeman, Montana.

Tipping bucket precipitation gages are at Onion Park and Stringer Creek, but only summer precipitation had been collected from 1993 to 1997.  In 1997, these gages were modified with a tipping bucket storage gage (TIPSTOR) to collect both frozen and non-frozen precipitation; however, this tipping bucket data has not been analyzed.

*The TIPSTOR is a storage type gage that mounts above the tipping bucket gage.  It has an antifreeze solution with an oil layer that floats atop the solution.  Overflow from this container is proportional to the precipitation that is falling; overflow is directed through the tipping bucket mechanism and measured similarly to rainfall passing through the tipping bucket.  The TIPSOR (Tipping Bucket Storage Gage) was developed by Farnes and McCaughey and reported in McCaughey and Farnes. (1996). [Measuring winter precipitation with an antifreeze-based tipping bucket system. In: Troendle, Charles, ed. 64th Annual Meeting of the Western Snow Conference; 1996 April 15-18; Bend, OR. Fort Collins, CO: Colorado State University: 130-136.]

## Name, Elevation and Period of Record for Precipitation Stations

| Precipitation Station | Elevation (ft) | Period of Record (WY) |
|---|---|---|
| **Tenderfoot Creek Experimental Forest** | | |
| *Bubbling Springs | 7,430 | 1993-present |
| *County Line | 7,810 | 1993-present |
| *Dry Park | 7,420 | 1993-present |
| *Farnes Meadow | 7,400 | 1993-present |
| *Lonesome Creek | 6,970 | 1993-present |
| *Onion Park | 7,410 | 1993-present |
| Passionate Creek | 6,250 | 1995-present |
| *Stringer Creek | 6,550 | 1993-present |
| *Sun Creek | 7,040 | 1993-present |
| Upper Stringer | 6,870 | 1997-present |
| **SNOTEL** | | |
| Deadman Creek | 6,450 | 1967-present |
| Spur Park | 8,100 | 1967-present |

*Eight original storage precipitation gages with average elevation of 7,254 ft. Average elevation of Tenderfoot Creek Experimental Forest is 7,236 ft and average elevation of Deadman Creek and Spur Park is 7,275 ft.

# Tenderfoot Creek Experimental Forest
## Monthly Precipitation*, inches

| Water Year | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Annual Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1967 | 1.4 | 2.8 | 3.6 | 8.0 | 5.0 | 4.3 | 3.8 | 2.3 | 4.7 | 0.9 | 0.9 | 1.8 | 39.3 |
| 1968 | 2.4 | 2.4 | 5.5 | 2.4 | 2.7 | 1.6 | 2.3 | 5.4 | 3.2 | 2.0 | 2.3 | 3.6 | 35.7 |
| 1969 | 1.2 | 3.2 | 2.2 | 5.7 | 1.6 | 1.2 | 2.3 | 2.2 | 3.5 | 1.6 | 3.9 | 1.1 | 29.5 |
| 1970 | 4.2 | 1.9 | 2.9 | 6.1 | 2.6 | 4.9 | 4.1 | 5.0 | 3.1 | 1.6 | 0.9 | 2.2 | 39.3 |
| 1971 | 1.2 | 3.5 | 2.5 | 6.2 | 3.3 | 4.2 | 3.9 | 2.5 | 2.7 | 1.4 | 2.0 | 0.8 | 34.2 |
| 1972 | 1.2 | 2.2 | 7.6 | 6.8 | 4.7 | 3.1 | 2.0 | 2.4 | 2.0 | 2.6 | 3.0 | 0.6 | 38.2 |
| 1973 | 1.0 | 1.5 | 3.0 | 1.8 | 1.1 | 2.0 | 2.8 | 1.6 | 2.7 | 2.0 | 2.3 | 2.4 | 24.0 |
| 1974 | 2.3 | 4.1 | 4.0 | 4.0 | 3.4 | 3.2 | 3.5 | 6.4 | 1.2 | 2.1 | 4.7 | 0.9 | 39.8 |
| 1975 | 1.1 | 1.8 | 4.3 | 5.2 | 1.9 | 3.6 | 3.9 | 4.5 | 6.9 | 2.2 | 2.9 | 1.7 | 40.1 |
| 1976 | 5.1 | 4.6 | 2.4 | 3.2 | 2.8 | 1.4 | 4.1 | 2.0 | 3.8 | 1.7 | 2.0 | 1.7 | 34.9 |
| 1977 | 0.4 | 2.9 | 3.0 | 3.1 | 1.9 | 4.5 | 2.2 | 3.6 | 1.7 | 2.7 | 1.6 | 1.8 | 29.3 |
| 1978 | 2.2 | 3.6 | 7.5 | 4.4 | 2.8 | 2.7 | 2.2 | 3.3 | 4.2 | 5.0 | 2.7 | 2.9 | 43.4 |
| 1979 | 0.3 | 3.3 | 4.7 | 2.2 | 3.8 | 1.8 | 2.8 | 1.6 | 4.4 | 1.1 | 1.4 | 0.6 | 28.1 |
| 1980 | 1.3 | 1.4 | 1.7 | 2.7 | 2.0 | 4.2 | 1.5 | 5.7 | 4.1 | 1.0 | 2.4 | 0.9 | 28.8 |
| 1981 | 3.5 | 1.4 | 3.0 | 1.1 | 2.0 | 3.4 | 2.7 | 6.7 | 4.0 | 2.9 | 0.7 | 0.5 | 32.0 |
| 1982 | 3.0 | 2.3 | 2.7 | 5.0 | 1.8 | 3.8 | 3.7 | 4.2 | 3.6 | 2.7 | 0.7 | 2.6 | 36.2 |
| 1983 | 1.0 | 2.5 | 3.6 | 1.9 | 2.0 | 3.3 | 2.3 | 3.0 | 3.9 | 3.6 | 0.6 | 2.9 | 30.6 |
| 1984 | 2.2 | 2.9 | 2.7 | 2.1 | 1.8 | 4.3 | 3.1 | 2.3 | 2.7 | 0.0 | 1.5 | 2.5 | 28.0 |
| 1985 | 2.4 | 2.8 | 3.1 | 1.2 | 3.0 | 3.5 | 2.2 | 2.6 | 1.2 | 0.2 | 4.1 | 5.6 | 31.9 |
| 1986 | 3.3 | 3.7 | 2.4 | 2.8 | 3.5 | 1.8 | 3.4 | 3.3 | 3.4 | 4.2 | 1.6 | 2.7 | 36.1 |
| 1987 | 0.7 | 2.5 | 1.2 | 1.3 | 1.4 | 3.1 | 0.5 | 4.5 | 0.9 | 3.5 | 0.8 | 1.0 | 21.3 |
| 1988 | 0.5 | 0.5 | 2.8 | 3.5 | 3.6 | 3.4 | 3.1 | 2.5 | 1.9 | 1.5 | 0.7 | 1.8 | 25.9 |
| 1989 | 1.7 | 1.9 | 3.3 | 5.0 | 1.8 | 3.9 | 3.1 | 2.5 | 3.7 | 3.4 | 3.6 | 2.0 | 35.8 |
| 1990 | 1.6 | 3.4 | 5.7 | 3.9 | 1.8 | 3.1 | 2.5 | 5.3 | 1.7 | 1.1 | 2.6 | 0.3 | 32.9 |
| 1991 | 2.2 | 2.5 | 3.5 | 3.8 | 1.1 | 4.5 | 7.0 | 5.6 | 2.1 | 1.0 | 0.6 | 2.6 | 36.4 |
| 1992 | 1.4 | 3.1 | 2.6 | 1.9 | 1.2 | 1.4 | 3.6 | 2.5 | 4.3 | 2.3 | 1.2 | 2.1 | 27.5 |
| 1993 | 1.8 | 2.0 | 2.4 | 2.9 | 1.3 | 2.2 | 3.3 | 4.3 | 6.2 | 8.7 | 7.1 | 2.7 | 44.9 |
| 1994 | 2.3 | 1.9 | 2.5 | 3.8 | 2.0 | 1.9 | 3.8 | 2.5 | 2.5 | 1.5 | 0.5 | 0.5 | 25.6 |
| 1995 | 0.5 | 3.2 | 1.7 | 3.1 | 1.1 | 3.5 | 4.3 | 4.1 | 6.2 | 5.1 | 2.3 | 2.5 | 37.6 |
| 1996 | 2.7 | 2.5 | 1.2 | 2.6 | 2.4 | 2.6 | 2.8 | 6.2 | 2.1 | 1.3 | 0.9 | 2.4 | 29.9 |
| 1997 | 1.4 | 2.6 | 4.4 | 2.4 | 2.6 | 2.7 | 2.6 | 4.7 | 5.8 | 2.8 | 3.8 | 1.3 | 36.9 |
| 1998 | 1.7 | 0.9 | 1.7 | 3.1 | 0.6 | 2.4 | 2.0 | 3.8 | 7.1 | 2.4 | 2.8 | 0.5 | 29.0 |
| 1961-1990 average: | 1.9 | 2.6 | 3.7 | 3.9 | 2.8 | 3.1 | 2.9 | 3.7 | 3.2 | 2.2 | 2.0 | 1.8 | 33.8 |

* Average of Bubbling Springs, County Line, Dry Park, Farnes Meadow, Lonesome Creek, Onion Park, Stringer Creek and Sun Creek storage gages. 1967-1992 and 1961-1990 averages estimated from Spur Park and Deadman Creek SNOTEL sites.

## Tenderfoot Creek Experimental Forest
## Historic Precipitation Estimates for Storage Gages
Monthly totals, inches (based on data through 6/98)

|  |  | $R^2$ |
|---|---|---|
| Average 8TCEF | = 0.98 x Average Spur Park and Deadman Creek ± 0 | .81 |
| Bubbling Springs | = 0.97 x Average 8TCEF + 0.1 | .96 |
| County Line | = 1.03 x Average 8TCEF + 0.1 | .94 |
| Dry Park | = 0.95 x Average 8TCEF + 0.1 | .99 |
| Farnes Meadow | = 1.07 x Average 8TCEF - 0.1 | .99 |
| Lonesome Creek | = 0.91 x Average 8TCEF ± 0 | .97 |
| Onion Park | = 1.04 x Average 8TCEF ± 0 | .99 |
| Passionate Creek | = 0.92 x Average 8TCEF - 0.3 | .96 |
| Stringer Creek | = 0.97 x Average 8TCEF - 0.1 | .96 |
| Sun Creek | = 1.03 x Average 8TCEF - 0.1 | .98 |
| Upper Stringer | = 1.03 x Average 8TCEF - 0.1 | .97 |

Average 8TCEF = Average monthly precipitation for Bubbling Springs, County Line, Dry Park, Farnes Meadow, Lonesome Creek, Onion Park, Stringer Creek, and Sun Creek
Spur Park = Monthly precipitation at Spur Park SNOTEL site
Deadman Creek = Monthly precipitation at Deadman Creek SNOTEL site

# Estimated 1961-1990 Average Monthly Precipitation, Inches

| Month | Station | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Bubbling Springs | County Line | Dry Park | Farnes Meadow | Lonesome Creek | Onion Park | Passionate Creek | Stringer Creek |
| Oct | 2.0 | 2.1 | 1.9 | 1.9 | 1.7 | 2.0 | 1.5 | 1.8 |
| Nov | 2.7 | 2.8 | 2.6 | 2.7 | 2.4 | 2.8 | 2.1 | 2.5 |
| Dec | 3.7 | 3.9 | 3.6 | 3.8 | 3.3 | 3.8 | 3.1 | 3.5 |
| Jan | 3.9 | 4.1 | 3.8 | 4.0 | 3.5 | 4.0 | 3.3 | 3.7 |
| Feb | 2.8 | 3.0 | 2.8 | 2.9 | 2.5 | 2.9 | 2.3 | 2.6 |
| Mar | 3.1 | 3.3 | 3.0 | 3.2 | 2.8 | 3.2 | 2.5 | 2.9 |
| Apr | 2.9 | 3.1 | 2.8 | 3.0 | 2.6 | 3.0 | 2.4 | 2.7 |
| May | 3.7 | 3.9 | 3.6 | 3.8 | 3.3 | 3.8 | 3.1 | 3.5 |
| Jun | 3.2 | 3.4 | 3.1 | 3.3 | 2.9 | 3.3 | 2.6 | 3.0 |
| Jul | 2.2 | 2.4 | 2.2 | 2.3 | 2.0 | 2.3 | 1.7 | 2.0 |
| Aug | 2.1 | 2.2 | 2.1 | 2.1 | 1.9 | 2.1 | 1.6 | 1.9 |
| Sep | 1.9 | 2.0 | 1.9 | 1.9 | 1.7 | 1.9 | 1.4 | 1.7 |
| Annual | 34.2 | 36.2 | 33.4 | 34.9 | 30.6 | 35.1 | 27.6 | 31.8 |

| Month | Sun Creek | Upper Stringer |
|---|---|---|
| Oct | 1.9 | 1.9 |
| Nov | 2.6 | 2.6 |
| Dec | 3.7 | 3.7 |
| Jan | 3.9 | 3.9 |
| Feb | 2.8 | 2.8 |
| Mar | 3.1 | 3.1 |
| Apr | 2.9 | 2.9 |
| May | 3.7 | 3.7 |
| Jun | 3.2 | 3.2 |
| Jul | 2.2 | 2.2 |
| Aug | 2.0 | 2.0 |
| Sep | 1.8 | 1.8 |
| Annual | 33.8 | 33.8 |

# Tenderfoot Creek Experimental Forest
## Equations for Estimating Missing Precipitation Data for Storage Gages
Monthly totals, inches (based on data through 6/98)

|  |  | $R^2$ |
|---|---|---|
| Bubbling Springs | = 1.00 x Dry Park + 0.1 | .93 |
|  | = 0.90 x Farnes Meadow + 0.2 | .94 |
|  | = 1.04 x Lonesome Creek + 0.1 | .93 |
|  | = 0.92 x Onion Park + 0.2 | .95 |
|  | = 0.92 x Sun Creek + 0.3 | .94 |
| County Line | = 1.08 x Dry Park ± 0 | .95 |
|  | = 0.97 x Farnes Meadow + 0.1 | .96 |
|  | = 0.98 x Onion Park + 0.1 | .93 |
| Dry Park | = 0.94 x Bubbling Springs + 0.1 | .93 |
|  | = 0.88 x County Line + 0.1 | .95 |
|  | = 0.89 x Farnes Meadow + 0.1 | .99 |
|  | = 0.91 x Onion Park + 0.1 | .98 |
|  | = 0.90 x Upper Stringer + 0.2 | .95 |
| Farnes Meadow | = 1.06 x Bubbling Springs ± 0 | .94 |
|  | = 0.99 x County Line ± 0 | .96 |
|  | = 1.11 x Dry Park - 0.1 | .99 |
|  | = 1.01 x Onion Park ± 0 | .98 |
|  | = 1.01 x Upper Stringer + 0.1 | .96 |
| Lonesome Creek | = 0.90 x Bubbling Springs ± 0 | .93 |
|  | = 0.91 x Stringer Creek + 0.2 | .96 |
|  | = 0.87 x Sun Creek + 0.2 | .97 |
| Onion Park | = 1.03 x Bubbling Springs ± 0 | .95 |
|  | = 0.95 x County Line + 0.1 | .93 |
|  | = 1.08 x Dry Park ± 0 | .98 |
|  | = 0.97 x Farnes Meadow + 0.1 | .98 |
|  | = 0.99 x Sun Creek + 0.2 | .96 |

## Estimating Equations for Missing Precipitation Data (continued)

| | | |
|---|---|---|
| Passionate Creek | = 0.99 x Lonesome Creek - 0.3 | .94 |
| | = 0.94 x Stringer Creek - 0.2 | .97 |
| Stringer Creek | = 1.05 x Lonesome Creek - 0.1 | .96 |
| | = 1.03 x Passionate Creek + 0.2 | .97 |
| | = 0.93 x Sun Creek ± 0 | .97 |
| | = 0.93 x Upper Stringer ± 0 | .97 |
| Sun Creek | = 1.02 x Bubbling Springs - 0.1 | .94 |
| | = 1.11 x Lonesome Creek - 0.1 | .97 |
| | = 0.97 x Onion Park - 0.1 | .96 |
| | = 1.04 x Stringer Creek ± 0 | .97 |
| | = 0.99 x Upper Stringer ± 0 | .98 |
| Upper Stringer | = 1.06 x Dry Park - 0.1 | .95 |
| | = 0.95 x Farnes Meadow ± 0 | .96 |
| | = 1.04 x Stringer Creek + 0.1 | .97 |
| | = 0.99 x Sun Creek + 0.1 | .98 |

## APPENDIX V.  HISTORIC MONTHLY STREAMFLOW FOR TENDERFOOT CREEK
BELOW STRINGER CREEK

Daily streamflow has been measured at Sheep Creek near White Sulphur Springs since 1942.  This drainage heads in the Little Belt Mountains about 12 miles ESE of Tenderfoot Creek headwaters.  There are some hydrologic differences between Sheep Creek and Tenderfoot Creek.  Timber harvesting has occurred in the Sheep Creek drainage which might also affect the relationship.  However, this is the only active long term streamflow measuring station on streams flowing out of the Little Belt Mountains that can be used for correlations.

Streamflows have been measured on Tenderfoot Creek Experimental Forest beginning with the 1993 WY.  For this report, only the Lower Tenderfoot station (Tenderfoot Creek below Stringer Creek) was analyzed.  Correlations and estimating equations were developed for monthly flows April through July.  The August and September flows were analyzed together as were the October through March flows.

Correlations, procedures and analyses are on file at the Forestry Sciences Laboratory in Bozeman, Montana.

Following are monthly flows for Tenderfoot Creek below Stringer Creek in acre-feet starting in 1942 WY.  The estimated flows (1942-1992) can be used to determine variability by month, season and year, but should be viewed with caution when referring to the streamflow for any specific month.

## Tenderfoot Creek Experimental Forest
## Tenderfoot Creek below Stringer Creek
## Monthly Streamflow in Acre-feet

| WY | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | sum Oct-Mar | sum Apr-Sept | sum Oct-Sept |
|------|-----|-----|-----|-----|-----|-----|------|------|------|------|------|------|------|-------|-------|
| 1942 | 100 | 80 | 75 | 70 | 65 | 70 | 162 | 2884 | 3441 | 322 | 251 | 141 | 460 | 7201 | 7661 |
| 1943 | 93 | 120 | 110 | 110 | 90 | 95 | 304 | 1750 | 3990 | 281 | 218 | 128 | 618 | 6671 | 7289 |
| 1944 | 120 | 115 | 110 | 105 | 100 | 110 | 142 | 1167 | 1402 | 300 | 204 | 150 | 660 | 3365 | 4025 |
| 1945 | 140 | 130 | 120 | 110 | 95 | 105 | 157 | 688 | 3738 | 281 | 210 | 187 | 700 | 5261 | 5961 |
| 1946 | 86 | 80 | 75 | 70 | 65 | 60 | 384 | 2592 | 3233 | 413 | 299 | 181 | 436 | 7102 | 7538 |
| 1947 | 203 | 131 | 75 | 70 | 65 | 75 | 154 | 3263 | 3823 | 281 | 244 | 177 | 619 | 7942 | 8561 |
| 1948 | 131 | 170 | 150 | 130 | 115 | 125 | 139 | 3453 | 3966 | 471 | 450 | 260 | 821 | 8739 | 9560 |
| 1949 | 233 | 169 | 130 | 115 | 100 | 110 | 177 | 2836 | 1919 | 315 | 175 | 136 | 857 | 5558 | 6415 |
| 1950 | 89 | 85 | 80 | 70 | 60 | 75 | 152 | 679 | 4304 | 394 | 365 | 212 | 459 | 6106 | 6565 |
| 1951 | 157 | 99 | 80 | 60 | 55 | 65 | 136 | 3115 | 3418 | 279 | 227 | 150 | 516 | 7325 | 7841 |
| 1952 | 93 | 40 | 85 | 75 | 70 | 80 | 287 | 3430 | 1515 | 381 | 187 | 121 | 443 | 5921 | 6364 |
| 1953 | 100 | 90 | 80 | 70 | 65 | 75 | 140 | 1786 | 3580 | 471 | 260 | 170 | 480 | 6407 | 6887 |
| 1954 | 70 | 60 | 50 | 50 | 50 | 70 | 143 | 1422 | 2207 | 289 | 191 | 138 | 350 | 4390 | 4740 |
| 1955 | 76 | 68 | 60 | 55 | 50 | 70 | 162 | 1150 | 4182 | 705 | 292 | 185 | 379 | 6676 | 7055 |
| 1956 | 125 | 110 | 103 | 100 | 95 | 120 | 136 | 2055 | 857 | 532 | 139 | 116 | 653 | 3835 | 4488 |
| 1957 | 105 | 78 | 60 | 40 | 38 | 70 | 150 | 2343 | 2366 | 300 | 191 | 143 | 391 | 5493 | 5884 |
| 1958 | 70 | 70 | 65 | 60 | 55 | 57 | 150 | 2234 | -20 | 506 | 147 | 106 | 377 | 3123 | 3500 |
| 1959 | 80 | 65 | 60 | 58 | 62 | 70 | 144 | 1793 | 4944 | 297 | 216 | 166 | 395 | 7560 | 7955 |
| 1960 | 163 | 63 | 43 | 55 | 50 | 63 | 143 | 1547 | 2106 | 390 | 193 | 141 | 447 | 4520 | 4967 |
| 1961 | 70 | 60 | 55 | 50 | 50 | 55 | 152 | 853 | 708 | 631 | 104 | 113 | 340 | 2561 | 2901 |
| 1962 | 100 | 80 | 75 | 70 | 65 | 70 | 151 | 2607 | 2961 | 328 | 218 | 143 | 460 | 6408 | 6868 |
| 1963 | 128 | 120 | 110 | 100 | 90 | 95 | 137 | 2049 | 3628 | 324 | 235 | 187 | 643 | 6560 | 7203 |
| 1964 | 125 | 115 | 110 | 105 | 100 | 110 | 140 | 3454 | 4818 | 407 | 299 | 231 | 665 | 9349 | 10014 |
| 1965 | 153 | 130 | 120 | 110 | 95 | 105 | 136 | 3410 | 3955 | 1685 | 490 | 425 | 713 | 10101 | 10814 |
| 1966 | 446 | 262 | 160 | 140 | 130 | 233 | 172 | 3296 | 2443 | 278 | 278 | 187 | 1371 | 6654 | 8025 |
| 1967 | 119 | 86 | 75 | 70 | 65 | 75 | 149 | 3109 | 3836 | 644 | 362 | 257 | 490 | 8357 | 8847 |
| 1968 | 197 | 170 | 150 | 130 | 115 | 125 | 136 | 3366 | 4582 | 388 | 375 | 242 | 887 | 9089 | 9976 |
| 1969 | 224 | 147 | 130 | 115 | 100 | 110 | 370 | 2395 | 620 | 278 | 227 | 170 | 826 | 4060 | 4886 |
| 1970 | 163 | 102 | 80 | 70 | 60 | 75 | 152 | 3339 | 4304 | 444 | 360 | 222 | 550 | 8821 | 9371 |
| 1971 | 150 | 96 | 63 | 60 | 55 | 65 | 136 | 3425 | 3628 | 285 | 229 | 177 | 489 | 7880 | 8369 |
| 1972 | 122 | 96 | 85 | 75 | 70 | 80 | 136 | 3125 | 4757 | 278 | 275 | 154 | 528 | 8725 | 9253 |
| 1973 | 100 | 90 | 80 | 70 | 65 | 75 | 136 | 461 | 442 | 375 | 189 | 150 | 480 | 1753 | 2233 |
| 1974 | 70 | 60 | 50 | 50 | 50 | 70 | 1147 | 3144 | 4749 | 512 | 388 | 235 | 350 | 10175 | 10525 |
| 1975 | 115 | 73 | 60 | 55 | 50 | 70 | 144 | 1728 | 2705 | 1674 | 461 | 237 | 423 | 6949 | 7372 |
| 1976 | 224 | 150 | 115 | 100 | 95 | 120 | 446 | 3131 | 2795 | 317 | 340 | 257 | 804 | 7286 | 8090 |
| 1977 | 109 | 66 | 46 | 40 | 38 | 70 | 287 | 3197 | 1704 | 315 | 206 | 164 | 369 | 5873 | 6242 |
| 1978 | 212 | 163 | 191 | 163 | 184 | 215 | 324 | 3217 | 4833 | 3546 | 617 | 407 | 1128 | 12944 | 14072 |
| 1979 | 319 | 197 | 247 | 178 | 163 | 200 | 285 | 3350 | 4347 | 403 | 332 | 231 | 1304 | 8948 | 10252 |
| 1980 | 178 | 169 | 147 | 120 | 99 | 253 | 163 | 862 | 1390 | 307 | 246 | 154 | 966 | 3122 | 4088 |
| 1981 | 230 | 197 | 209 | 150 | 181 | 236 | 156 | 3379 | 3593 | 295 | 253 | 171 | 1203 | 7847 | 9050 |
| 1982 | 172 | 147 | 242 | 115 | 106 | 89 | 140 | 2360 | 4854 | 772 | 391 | 260 | 871 | 8777 | 9648 |
| 1983 | 271 | 259 | 265 | 256 | 221 | 224 | 139 | 1373 | 1834 | 717 | 481 | 242 | 1496 | 4786 | 6282 |
| 1984 | 227 | 188 | 166 | 288 | 227 | 332 | 237 | 2900 | 3217 | 278 | 255 | 193 | 1428 | 7080 | 8508 |
| 1985 | 135 | 200 | 96 | 119 | 109 | 271 | 1100 | 2534 | 800 | 477 | 299 | 264 | 930 | 5474 | 6404 |
| 1986 | 419 | 378 | 163 | 150 | 169 | 200 | 534 | 3440 | 4463 | 330 | 315 | 308 | 1479 | 9390 | 10869 |
| 1987 | 265 | 212 | 209 | 175 | 147 | 194 | 146 | 650 | 600 | 575 | 116 | 127 | 1202 | 2214 | 3416 |
| 1988 | 419 | 280 | 250 | 200 | 150 | 166 | 136 | 2435 | 700 | 537 | 123 | 108 | 1465 | 4039 | 5504 |
| 1989 | 80 | 70 | 65 | 55 | 50 | 75 | 155 | 2343 | 2237 | 315 | 244 | 206 | 395 | 5500 | 5895 |
| 1990 | 141 | 236 | 125 | 125 | 112 | 178 | 541 | 3217 | 4323 | 297 | 294 | 212 | 917 | 8884 | 9801 |
| 1991 | 218 | 112 | 102 | 99 | 131 | 131 | 136 | 3407 | 4560 | 286 | 251 | 193 | 793 | 8833 | 9626 |
| 1992 | 206 | 102 | 125 | 119 | 89 | 119 | 137 | 400 | 420 | 359 | 199 | 170 | 760 | 1685 | 2445 |
| 1993 | 92 | 83 | 80 | 74 | 61 | 74 | 144 | 3292 | 1962 | 2845 | 1398 | 1172 | 464 | 10813 | 11277 |
| 1994 | 571 | 444 | 417 | 376 | 287 | 240 | 1121 | 3861 | 993 | 396 | 234 | 196 | 2336 | 6801 | 9137 |
| 1995 | 162 | 184 | 151 | 139 | 116 | 118 | 121 | 1313 | 4912 | 1292 | 400 | 254 | 870 | 8292 | 9162 |
| 1996 | 239 | 207 | 193 | 174 | 144 | 142 | 253 | 2841 | 3864 | 552 | 282 | 179 | 1099 | 7971 | 9070 |
| 1997 | 221 | 210 | 193 | 179 | 114 | 123 | 176 | 3424 | 4335 | 672 | 396 | 256 | 1040 | 9259 | 10299 |
| 1998 | 229 | 198 | 193 | 179 | 114 | 129 | 230 | 2111 | 2520 | 1306 | 424 | 249 | 1042 | 6840 | 7882 |

1961-1990 average:

| | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct-Mar | Apr-Sept | Oct-Sept |
|---|-----|-----|-----|-----|-----|-----|-----|------|------|-----|-----|-----|-----|------|------|
| | 189 | 153 | 131 | 117 | 107 | 141 | 273 | 2605 | 2994 | 600 | 300 | 214 | 838 | 6986 | 7826 |

1942-1992 estimated from Sheep Creek near White Sulphur Springs